A REVIEW OF THE GEOLOGY AND MINERAL RESOURCES OF SOUTH AFRICA

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Abstract

South Africa is the Southernmost Sovereign State in Africa. Cape Town, the capital is the southernmost point of the African continent. It completely surrounds an independent state, the kingdom of Lesotho, but it's bounded by the Atlantic and Indian Oceans on the south and east respectively. On the north it's bounded by Namibia, Botswana and Zimbabwe; and on the east and northwest by Mozambique and Swaziland. It has an area of about 1.2 million Square kilometers and also surrounded by cornice of mountains in the east, south and west known as the great escarpment. The major geologic units in South Africa include: The Transvaal Basin (over 2.3 billion years old and host the oldest rock on earth). Bushveld igneous complex and Transvaal Supergroup and Kalahari Craton are some of the subunits; Witwatersrand Basin (2700 – 3100 million years old); Cape metamorphic province; Cape Supergroup (500 – 1100 million years old); Karoo Basin (geologic million years ago comprising Karoo tectonosm (breaking up of Pangaea) and Karoo Supergroup); Ilitenhage Group/ Cape flats (<145 million years old; Cenozoic sediments).The complex geology of South Africa (volcanism, tectonosm and sedimentation) contributed to its accumulation of various solid minerals (over 30 of them are currently officially mined). The Bushved Igneous Complex contains the world's largest reserve of Platinum Group metals (platinum, palladium, Osmium, iridium, rhodium and ruthenium) and associated copper, nickel and cobalt mineralization; along with vast quantities of iron, tin, chromium, titanium and vanadium. Karoo Supergroup is known for its large deposits of bituminous and anthracite coal resources. The Witwatersrand Basin is also known for its vast deposit of gold, uranium, silver and pyrite. The Transvaal Supergroup equally has large deposits of iron and manganese. South Africa is the world's largest producer of chromium, manganese, platinum, Titanium and vermiculite in 2017. It's also the second world's largest producer of fluorspar and ilmenite (iron, palladium, rutile and zirconium). The mining industry is the cornerstone of South Africa's economy contributing about 30% of Gross Domestic Products (GDP). Sales of primary mineral products account for 50% of total export revenue. South Africa's mineral wealth as at 2010 has been estimated to be $4.71 trillion. Many mining companies operate in South Africa, employing over 1,000,000 workers (job creation).

Keywords: South Africa, Witwatersrand Basin, Karoo Supergroup, *mining industry*, Bushved Igneous Complex, Kalahari Craton, Solid Minerals.

1.0 Introduction

South Africa is the southernmost medium sized country in Africa with nine (9) provinces and a total land area of slightly more than 1.2 million square kilometres, making it roughly the same size as Niger, Angola, Mali and Colombia. It is one – eighth the size of the United States, twice the size of Germany. South Africa measures about 1600km from north to south and roughly the same from east to west,*(Big Media, 2010).*Going from west to east, South Africa shares long northern borders with Namibia and Botswana, touches Zimbabwe, has a strip of border with Mozambique and finally curves in around Swaziland before re-joining Mozambique's southern border. In the interior, nestled in the curve of the bean shaped Free State is the smallest mountainous country of Lesotho, completely surrounded by South Africa territory. South Africa is the continent's biggest economy and it is blessed with the world's largest natural resources of gold, platinum group metals, chrome ore and manganese ore, and also the first, second and third largest resources of titanium, zirconium and vanadium respectively *(Superior Mining International Corporation)*. The country's mining sector accounts for about one-third of the country's GDP. Historically, South Africa has been the largest producer of gold in the world with 98% of the country's gold believed to have been produced from goldfield located in Witwatersrand basin *(Superior Mining International Corporation*). The gold is recovered from ancient sedimentary conglomerate bands or reefs found mainly in the Central Rand Group in the upper Witwatersrand. One may wonder why and how these abundant mineral concentrate in South Africa, enriching the continent. However, the results of the tectonism and intrusions that occurred between the African plate and the South America's plate is the most cause.

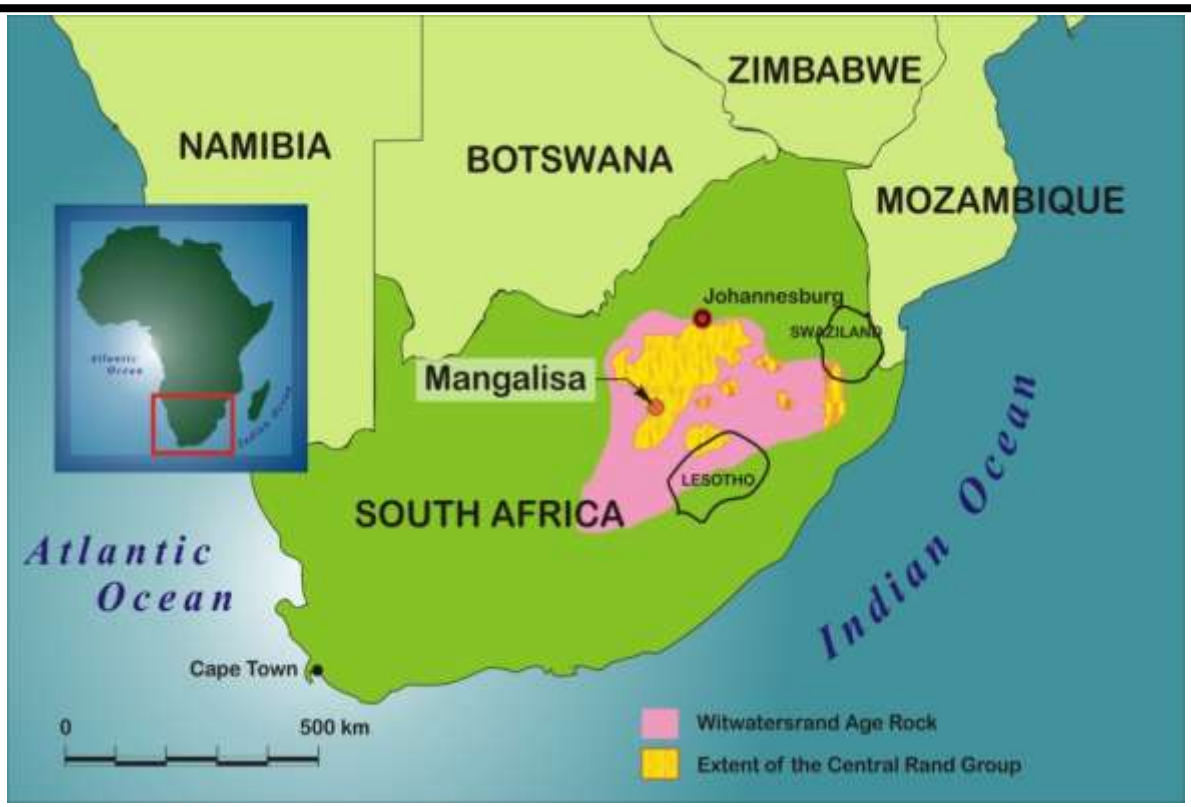


Fig 1.0 Map of South Africa and Witwatersrand Basin
(Source:superiormining.com/properties/south_africa/)

Fig 2.0 South Africa Map and Satellite Image (Source: http://geology.com/world/south-africa-satellite-image.shtml)

2.0 Climate

South Africa is largely a dry country, with most of its western regions being semi-desert. The rainfall increases in the east, (the Highveld, KwaZulu-Natal, and the Eastern Midlands), and falls primarily in summer. The narrow southern coastal strip receives all-year rainfall in the east (the Garden Route), and winter rainfall in the west (on the Cape Peninsula and its surrounds). The summers are warm to hot, while the winter temperatures can vary, depending on locality from bitterly cold to cool. Thus the Karoo, which occupies a large part of the western Central Plateau, has a climate which is extremely hot in summer and bitterly cold in winter. In contrast, the eastern coastline on the Indian Ocean is lush, well watered and warmed by the Mozambique Current; patches of Southern Africa mangroves grow along this coast. The southern coast, part of which is known as the Garden Route, is temperate and green. The Cape Peninsula and surrounds have a Mediterranean climate, with cool, wet winters and warm, dry summers (becoming hotter in interior valleys). Snow commonly falls in winter on the higher ground of the Cape Fold Mountains, during winter. The Cape Peninsula has a reputation for its wind: the dry "South-Easter" which blows almost incessantly in summer (December–February), and the "North-Wester" which accompanies the cold fronts that roll in from the Atlantic during winter (June–August). The vegetation of the Cape area consists of fynbos, some grassland and Albany thickets.

The eastern section of the Karoo does not extend as far north as the western part, giving way to the flat landscape of the Free State, which – though still semi-arid – receives somewhat more rain. North of the Vaal River the Highveld is better watered, with an annual rainfall of 760 mm (29.9 in) and a high altitude (around 1,750 m (5,741 ft) which mitigates against the extreme of heat of an inland area at this latitude. Winters are cold, though snow is rare.

Further north and to the east, especially where a drop in altitude beyond the escarpment gives the Lowveld its name, the temperature rises. The Tropic of Capricorn slices through the extreme north. Here one finds the typical South African Bushveld.

There is skiing in winter in the high mountainous regions: the Drakensberg mountains that form the eastern escarpment along the KwaZulu-Natal/Lesotho border, and on the Hex River Mountains of the Cape Fold Belt, but the coldest place in the country is Sutherland in the western Roggeveld region of the Upper Karoo, with minimum midwinter temperatures as low as −15 °C. The deep interior provides the hottest temperatures: in 1948 the mercury hit 51.7 °C (125.06 °F) in the Northern Cape Kalahari near Upington *(Geography of South Africa, wikivividly.com).*

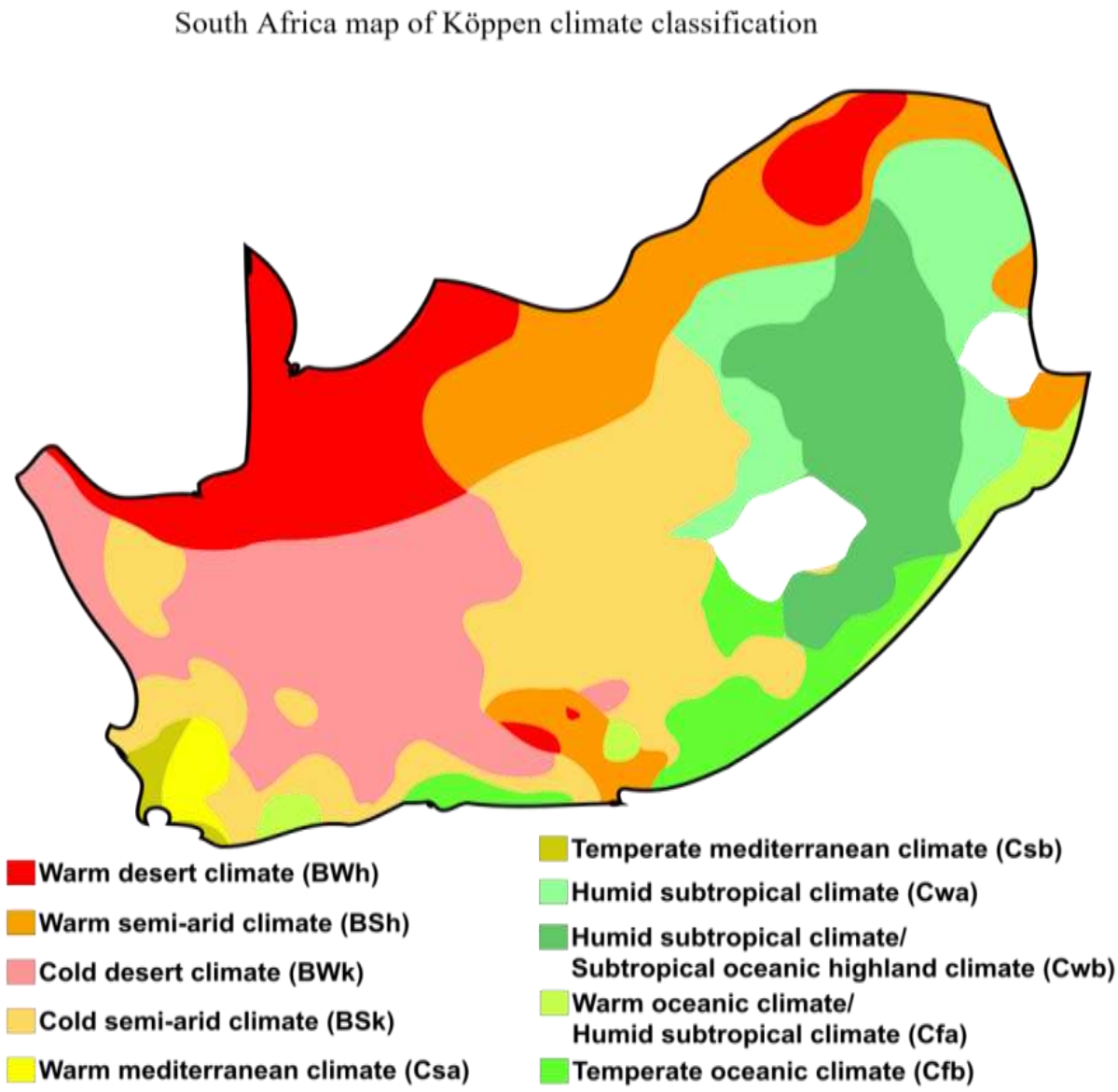


Fig 3.0 South Africa Map of Koppen Climate Classification
(Source::https://en.wikipedia.org/wiki/Geography_of_South_Africa#/media/File:South_Africa_map_of_K%C3%B6ppen_climate_classification.svg

3.0 Geology of South Africa

3.1- Relief and Topographic Setting

South Africa is the southernmost part of the African continent made up of nine provinces with a very old landmass enriched in mineral resources. The country is surrounded by a cornice of mountains in the east, west and south which is known as the Great Escarpment.

Fig 4. The relief/topographical map of South Africa (Source: http://www.southafrica-travel.net/Medaia/Geomap.gif)

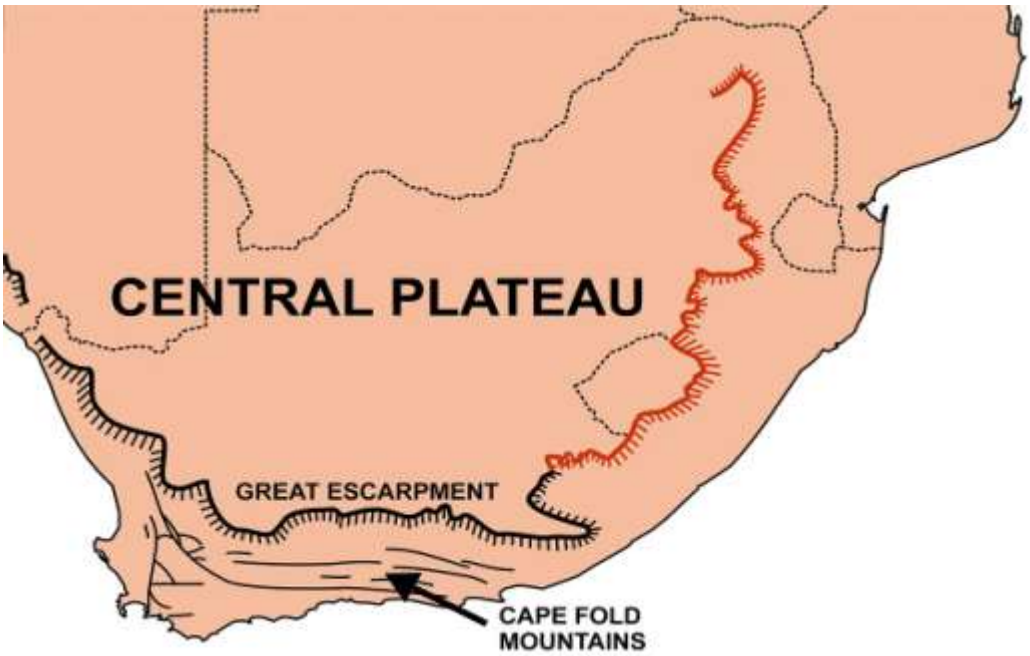


Fig 5. Relief/Central high Plateau topography of South Africa (Source: https://en.wikipedia.org/wiki/Great_Escarpment,_Southern_Africa

In the east in the area of Drakensberg of natal and in the kingdom of Lesotho, it reaches heights of almost 4000 meters. In the south and west, the highest peak is at about 2000 meters. (See Fig 5.0).

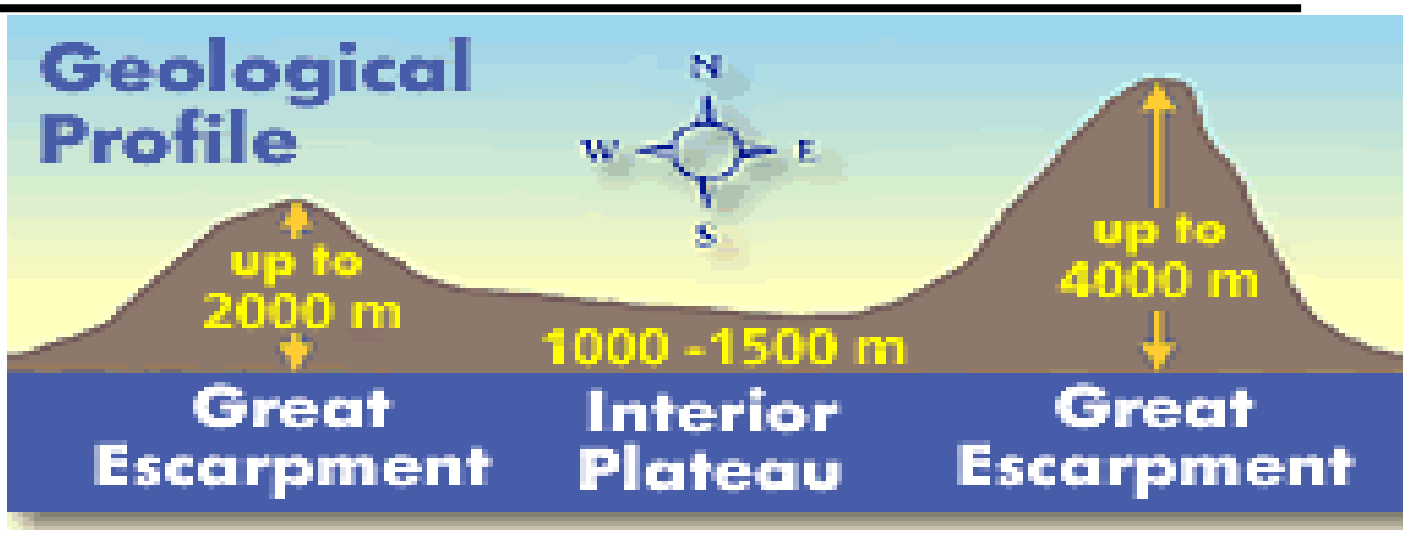


Fig 6 Geologic Profile (cross section) of South Africa (courtesy of http://www.southafrica-travel.net/pages/e_geolog.htm)

In front of the escarpment, there is a partially very narrow coastal strip, which is called the Lowveld (see Fig 4.0). After crossing the escarpment, one gets to the Central High Plateau of South Africa, called the Highveld. It has heights of between 1000 and 1700 meters. It slowly declines towards the north, to the Kalahari basin that does not have an outlet. Because the surrounding mountain chains form a catchment area for the clouds from the sea, the precipitation on the Highveld is low which results in arid, semi-desert conditions. South Africa has a long and complex geological history dating back more than 3700 billion years. Significant fragments of this geology have been preserved and along with them, mineral deposits. The preservation of so much Archaen geology dating back more than 2500 million years has resulted in the Archaen Witwatersrand Basin as well as several greenstone belts, being preserved. In the Western Cape Province of South Africa, the oldest rocks are gneiss and granite of the Mokolian Namaque-Natal metamorphic province (-1100 million years old) exposed north of Vredenal. These rocks are overlain by the Gariep Supergroup rocks which are approximately 650 million years old and similar-aged rocks of the Malmesbury Group. The Kaaimans and Congo Group in the south-western and southern parts of the province respectively. The Malmesbury and Kaaimens group are intruded by the 550 – 510 million years old Cape granite suite. The slightly younger Vanishysdrop Group occurs in the north-western part and the Klipheuwal Group in the south-western part of the province. Therocks of the Table Mountain, Bokkeveld and Witteberg Group of the Cape Supergroup follow unconformably upon the older rocks described above the younger Dwyka, Ecca and Beaufort Group of the Karoo Supergroup were deposited from300 to 255 million years ago in the northeastern part of the province.

Rocks of the Karoo Supergroup and older strata were tectonically deformed during the cape orogeny, which ended about 215 million years ago and was followed by uplift and intrusion of a vast network of dykes and sills of the Karoo dolerite suite into the Karoo rocks some 180 million years ago. Fluvial Sandstone and gravel overlaid by lacustrine day of the 145 million years old. Uitenhage Group occupy small fault bonded basins between Worcester and

Plettenberg Bay. The youngest geological formation is the Cenozoic sediments, which consist of fluvial, marine and predominantly windblown sandy deposites. They are assigned to the sandveld Group of the Western coastal plain and the Bredasdorp Group on the southern coastal plain.

3.2 Tectonic Setting

3.2.1 General Statement/Introductory note

A rift developed about 510 million years ago, separating Southern Africa from the Falkland Plateau. Flooding of the rift formed the Agylhas Sea. The sediment which accumulated in the shallow sea consolidated to form the Cape Supergroup of rocks (see fig 7.0), which forms the Cape Fold Belt today. This portion of Gondwana was probably located on the opposite side of the South Pole from Africa's present position, but compass bearings are nevertheless given as if Africa was in its present position *(Jackson and Stone, 2008).*

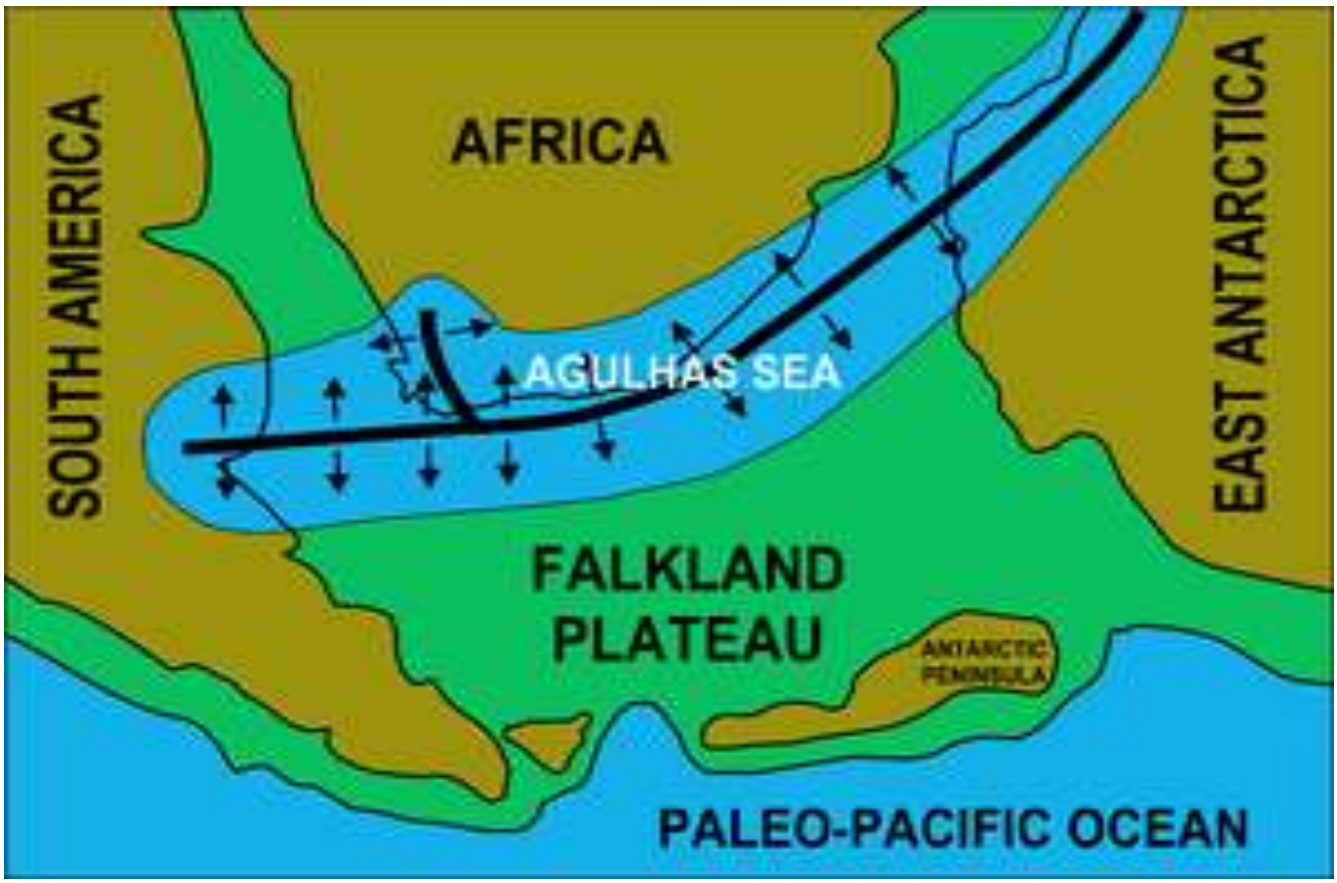


Fig 7: Southern Gondwana during the Cambrian-Ordovician Periods. Today's continents into which this supercontinent eventually broke up, are indicated in brown. A rift developed about 510 million years ago, separating Southern Africa from the Falkland Plateau. Flooding of the rift formed the Agulhas Sea. The sediments which accumulated in this shallow sea consolidated to form the Cape Supergroup of rocks, which form the Cape Fold Belt today. This portion of Gondwana was probably located on the opposite side of the South Pole from Africa's present position, but compass bearings are nevertheless given as if Africa was in its present position. (Southern Gondwana" by Oggmus - Own work. Licensed under Creative

Commons Attribution-Share Alike 3.0 via Wikimedia - http://commons.wikimedia.org/wiki/File:Southern_Gondwana.png#mediaviewer/File:Southern_Gondwana.png)

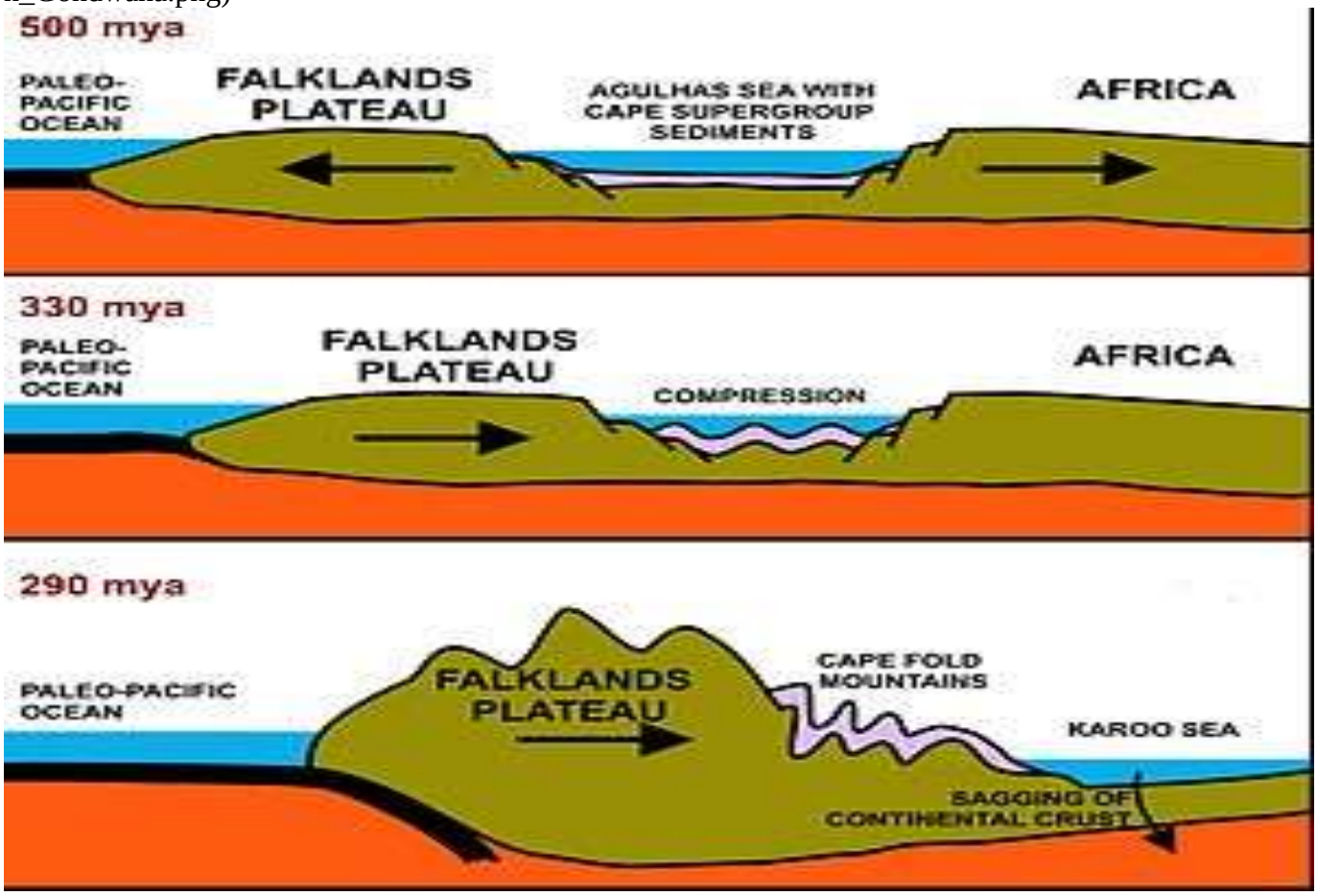


Fig 8: A north-south cross-section through the Agulhas Sea (see above). The brown structures are continental plates, the thick black layer on the left is paleo-Pacific Oceanic plate, red indicates the upper mantle, and blue indicates flooded areas or ocean. The top illustration depicts the geology about 510 million years ago, with the sediments which would eventually form the Cape Supergroup settling in the Agulhas Sea. The middle illustration depicts the Falkland Plateau drifting northwards once again to close the Agulhas Sea, causing the Cape Supergroup to be rucked into a series of folds, running predominantly east-west. The lowest illustration shows how subduction of the paleo-Pacific Oceanic plate under the Falkland Plateau, during the Early Permian period, raised a massive range of mountains. These eventually eroded into the Karoo Sea, forming the Karoo Supergroup. Ultimately, the Falkland Mountains eroded almost completely away, but the Cape Fold Mountains had, by this time, become buried under the Karoo sediments. Being composed largely of quartzitic sandstone, they resisted subsequent erosion, when continental uplifting caused several kilometers of Southern Africa's surface to be planed away, and thus persist to this day as the Cape Fold Belt. The remnant of the Falkland Plateau broke away from Africa, and drifted south-westwards to its present position in the western South Atlantic Ocean, following the breakup of Gondwana about 150 mya

(*http://commons.wikimedia.org/wiki/File:Formation_of_Cape_Fold_Mountains.jpg#mediaviewer/File:*Formation_of_Cape_Fold_Mountains.jpg).

The tectonic setting as seen in fig 8.0 shows that; i) The top illustration depicts the geology about 510 million years ago with the sediments which would eventually form the Cape Supergroup setting Agulhas Sea. ii) The middle illustration depicts Falkland Plateau drifting northwards ones again to close the Agulhas Sea, causing the Cape Supergroup rucked into a series of folds, running predominantly east-west. iii) The lowest illustration shows how subduction of the paleo-Pacific Oceanic plate under the Falkland Plateau, during the Early Permian period, raised a massive range of mountains. These eventually eroded into the Karoo Sea, forming the Karoo Supergroup.

A north-south cross-section through the Agulhas Sea (see Fig 8.0 above). The brown structures are continental plates, the thick black layer on the left is paleo-Pacific Oceanic plate, red indicates the upper mantle, and blue indicates flooded areas or ocean. The top illustration depicts the geology about 510 million years ago, with the sediments which would eventually form the Cape Supergroup settling in the Agulhas Sea. The middle illustration depicts the Falkland Plateau drifting northwards once again to close the Agulhas Sea, causing the Cape Supergroup to be rucked into a series of folds, running predominantly east-west. The lowest illustration shows how subduction of the paleo-Pacific Oceanic plate under the Falkland Plateau, during the Early Permian period, raised a massive range of mountains. These eventually eroded into the Karoo Sea, forming, especially, the Beaufort Group of the Karoo Supergroup.

About 330 million years ago Gondwana had drifted over the South Pole (Norman and Whitfield, 2006), with the result that an ice sheet several kilometers thick covered much of Africa, and other parts of Gondwana (McCarthy and Rubridge, 2005). The glacial deposits from this ice sheet were the first of the sediments to be deposited to the north of the Cape Fold Mountains (and partially over these incipient mountains). The basin into which these sediments settled was deepest immediately north of the Cape Fold Mountain ranges. The ice sheet therefore floated on an inland lake, termed the Karoo inland sea, into which icebergs which had calved off the glaciers and ice sheet to the north deposited vast quantities of mud and rocks of various sizes and origins. Such deposits are known as tillite (Truswell,1977). Further north, the ice sheet was grounded also leaving diamictite deposits whenever it partially melted, but, in addition, it scoured the bedrock, leaving behind striations (scratch marks) which can be seen near Barkly West in the Northern Cape, and in the grounds of the University of KwaZulu-Natal. This layer of tillite, traces of which can be found over a wide area of Southern Africa, India, and South America provided crucial early evidence in support of the Theory of Continental Drift. In South Africa the layer is known as the *Dwyka Group*. It is the earliest and lowermost of the Karoo Supergroup of sedimentary deposits (Catuneanu et al, 2005).

3.2.2 Origin of Sediment Deposition

About 510 million years ago a rift valley developed across Southern Gondwana, just south of Southern Africa, but extending westward into South America, and eastward into Eastern Antarctica and possible even into Australia (Compton, 2004; Shone and Booth, 2005). An 8 km thick layer of sediment, known as the Cape Supergroup, accumulated on the floor of this rift valley. Closure of the rift valley, starting 330 million years ago, resulted from the development of a subduction zone along the southern margin of Gondwana, and the consequent drift of the Falkland Plateau back towards Africa, during the Carboniferous and early Permian periods. After closure of the rift valley, and compression of the Cape Supergroup into a series of parallel folds, running mainly east-west, the continued subduction of the paleo-Pacific Plate beneath the Falkland Plateau and the resulting collision of the latter with Southern Africa, raised a mountain range of immense proportions to the south of the former rift valley. The folded Cape Supergroup formed the northern foothills of this mountain range.

The weight of the Falkland-Cape Supergroup Mountains caused the continental crust of Southern Africa to sag, forming a retroarc foreland system, which became flooded to form the Karoo Sea. Sedimentation, beginning with glacial deposits from the north, but later from the Falkland Mountains to the south, into this depression formed the **Karoo Supergroup** (see fig 9.0 below).

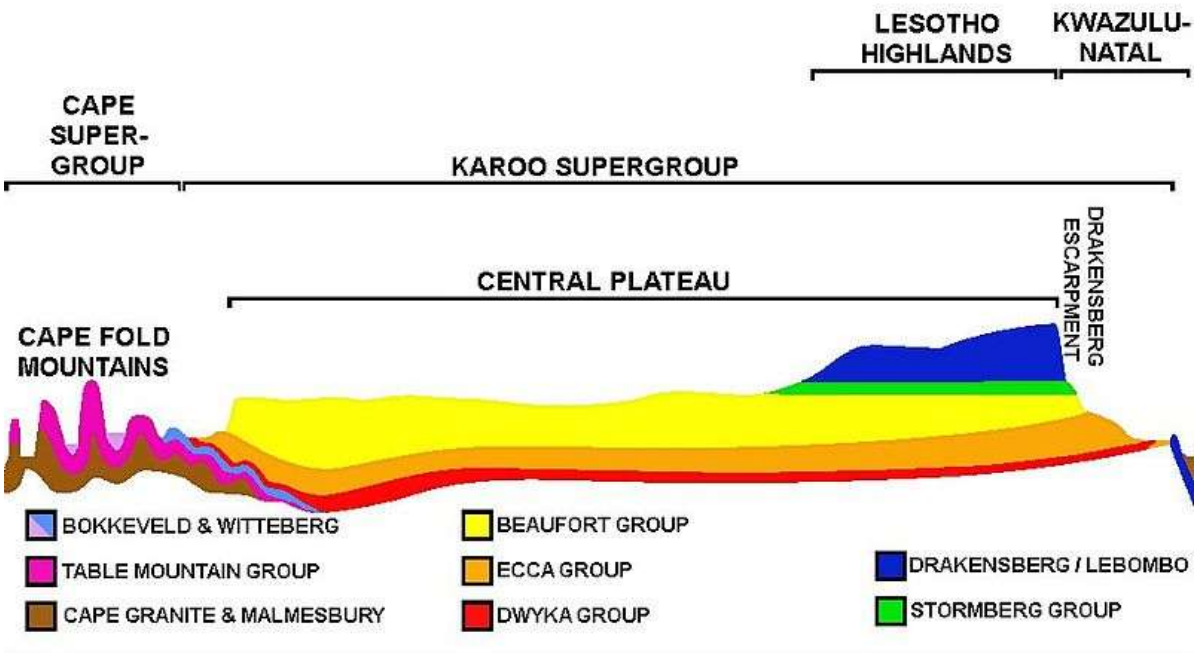


Fig9. An approximate SW-NE geological cross section through South Africa, with the Cape Peninsula (with Table Mountain) on left, and north-eastern KwaZulu-Natal on the right and is aged approximately 120 Million Years.

3.2.2.1 Karoo Supergroup

Is the most widespread stratigraphic unit in Africa south of the Sahara Desert. The supergroup consists of a sequence of units, mostly of nonmarine origin, deposited between the Late Carboniferous and Early Jurassic (Tab 1.0), a period of about 120 million years ago (see fig 9.0 and 12) when South Africa separated from South America.

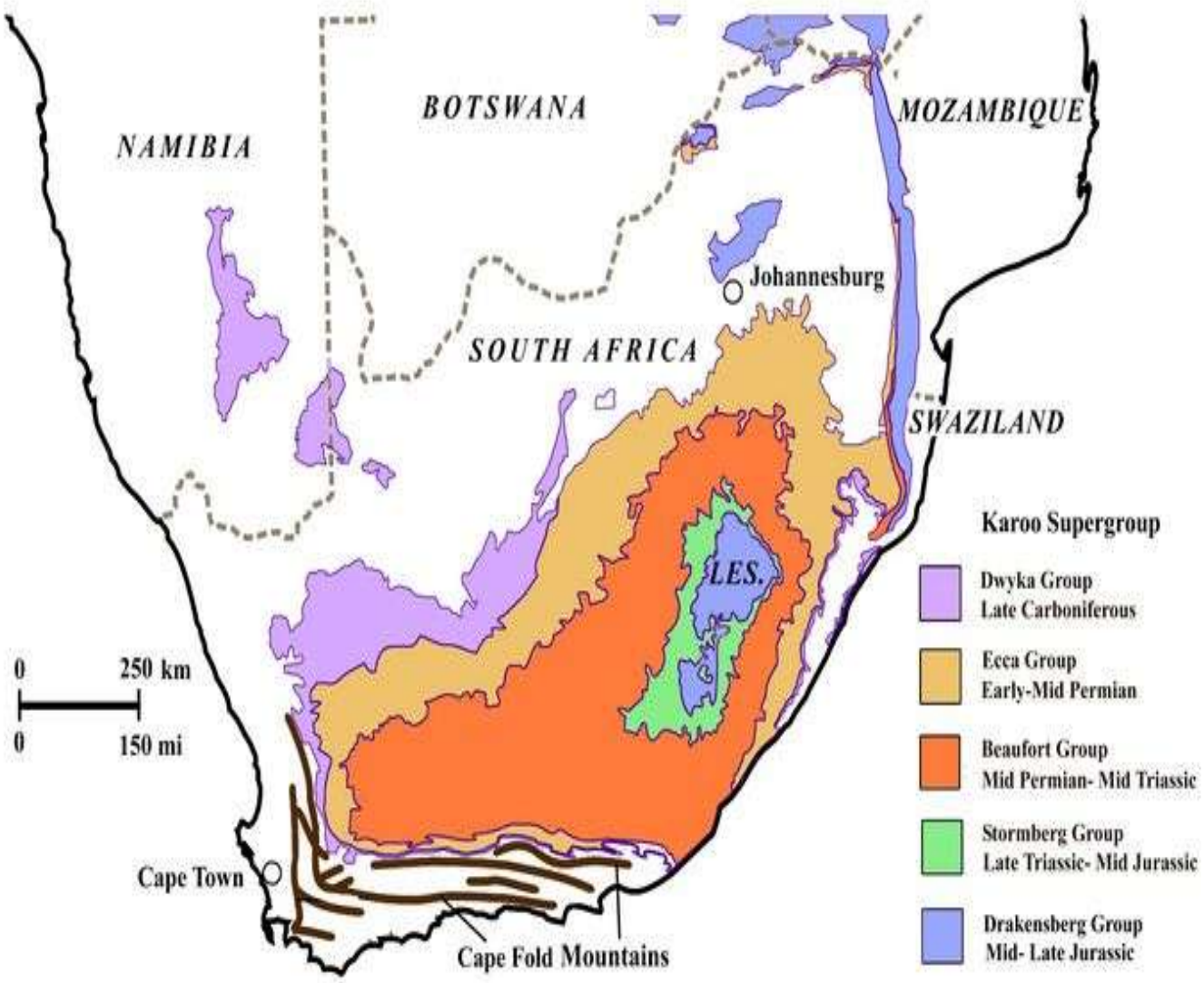


Fig 10*Geological map of the Karoo Supergroup* (Source: http://www.traveller24.com/MyTravels/is-this-really-how-capetonians-perceive-south-africa-20160627)

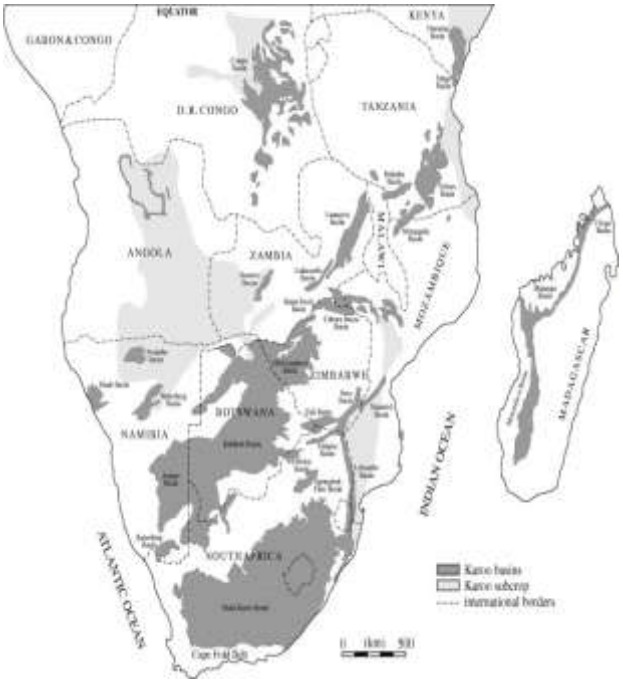


Fig. 11 The distribution of Karoo basins in South-central Africa (source: https://ars.els-cdn.com/content/image/1-s2.0-S1464343X05001184-gr1.jpg)

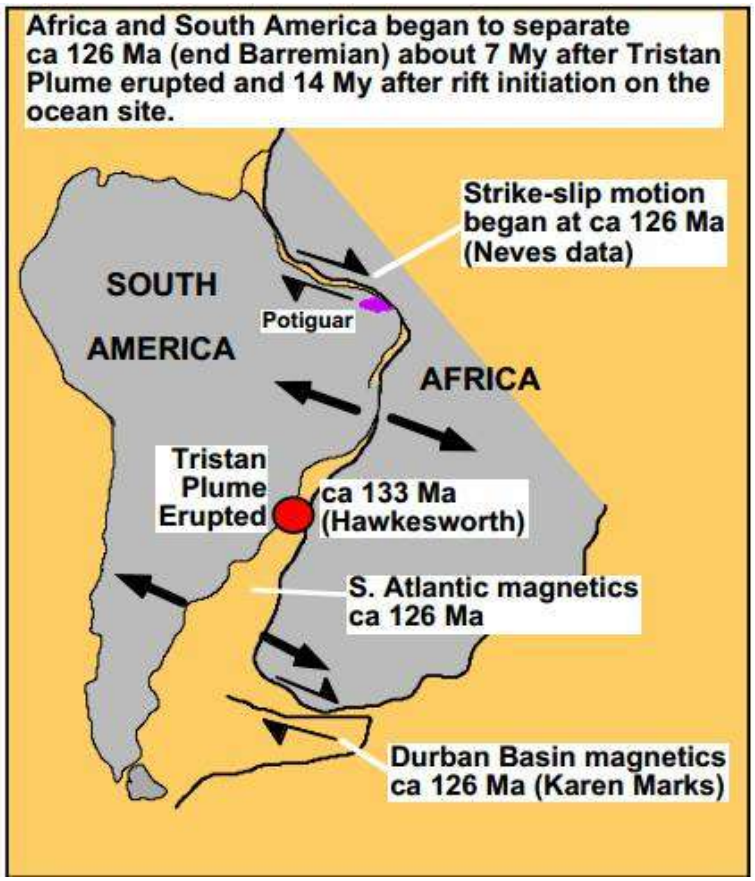
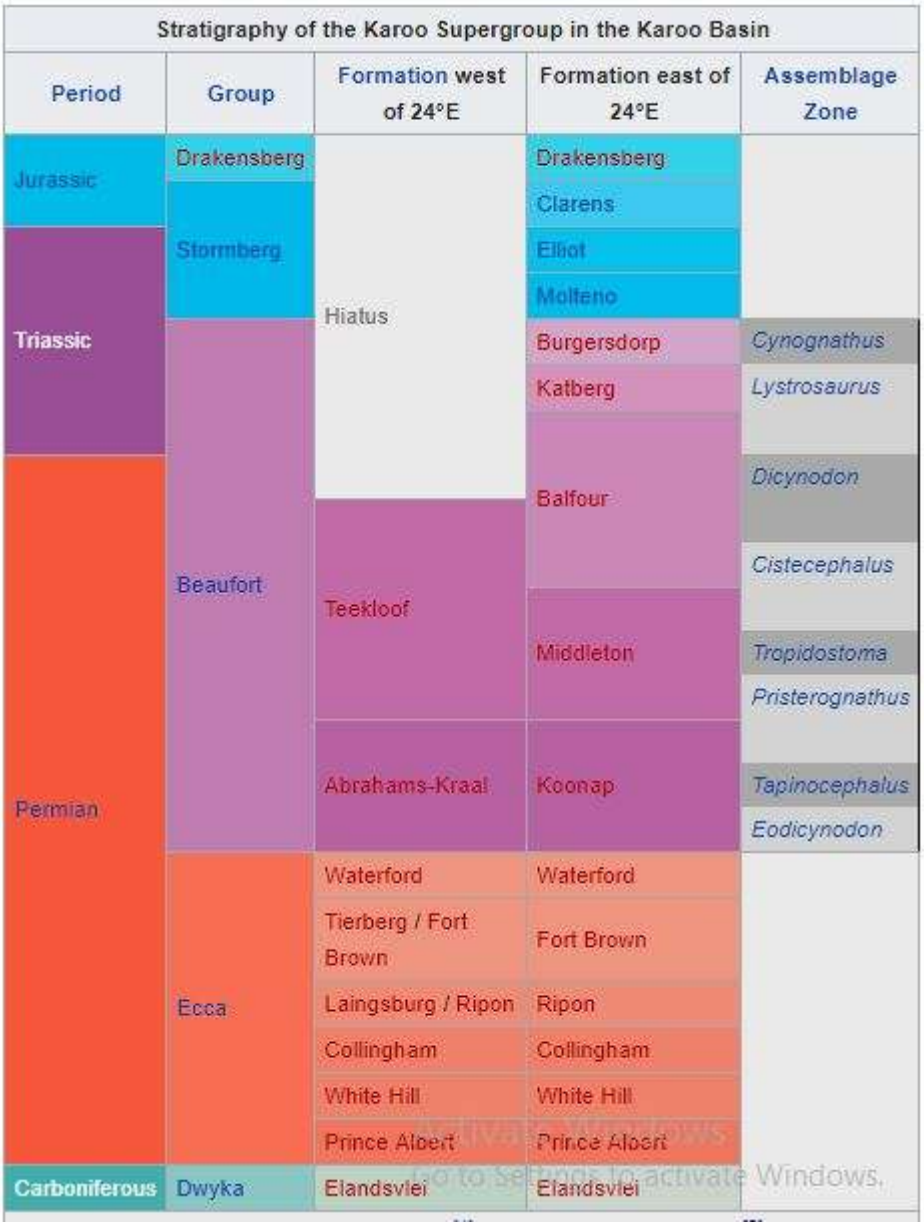


Fig 12 Map Showing the separation between South Africa and Africa

Table 1.0 The Karoo Supergroup Stratigraphy



Stratigraphy of the Karoo Supergroup in the Karoo Basin				
Period	Group	Formation west of 24°E	Formation east of 24°E	Assemblage Zone
Jurassic	Drakensberg	Hiatus	Drakensberg	
	Stormberg		Clarens	
			Elliot	
			Molteno	
Triassic	Beaufort		Burgersdorp	*Cynognathus*
			Katberg	*Lystrosaurus*
Permian		Teekloof	Balfour	*Dicynodon*
				Cistecephalus
			Middleton	*Tropidostoma*
				Pristerognathus
		Abrahams-Kraal	Koonap	*Tapinocephalus*
				Eodicynodon
	Ecca	Waterford	Waterford	
		Tierberg / Fort Brown	Fort Brown	
		Laingsburg / Ripon	Ripon	
		Collingham	Collingham	
		White Hill	White Hill	
		Prince Albert	Prince Albert	
Carboniferous	Dwyka	Elandsvlei	Elandsvlei	

References: Rubidge (2005), Selden and Nudds (2011)**(**https://en.wikipedia.org/wiki/Karoo_Supergroup#cite_note-EFE-2)

In southern Africa, rocks of the Karoo Supergroup cover almost two thirds of the present land surface (see Fig 10and 11), including all of Lesotho, almost the whole of Free State, and large parts of the Eastern Cape, Northern Cape, Mpumalanga and KwaZulu-Natal Provinces of South Africa. Karoo supergroup outcrops are also found in Namibia, Swaziland, Zambia, Zimbabwe and Malawi, (see Fig 10), as well as on other continents that were part of Gondwana. The basins in which it was deposited formed during the formation and breakup of Pangea (Catuneanu et al, 2005).The type area of the Karoo Supergroup is the Great Karoo in South Africa, where the most extensive outcrops of the sequence are exposed. Its strata which consist mostly of shales and sandstones, record an almost continuous sequence of marine glacial to terrestrial deposition from the Late Carboniferous

to the Early Jurassic. These accumulated in a retroarc foreland basin called the "main Karoo Basin". This basin was formed by the subduction and orogenesis along the southern border of what eventually became Southern Africa, in southern Gondwana. Its sediments attain a maximum cumulative thickness of 12km, with the overlying basaltic lavas (the Drakensberg Group) at least 1.4 km thick (Adelmann and Fiedler, 1996).Fossils include plants (both macro-fossils and pollen), rare insect and fish, common and diverse tetrapods (mostly the rapid reptiles, temnospondyl amphibians, and in the upper strata dinosaurs), and ichnofossils. Their biostratigraphy has been used as the international standard for global correlation of Permian to Jurassic nonmarine strata. Below are the various geological formations in South Africa (Hancox and Rubidge, 1997). See (Fig 9, 10 and Tab 1).

3.2.2.2 The Abrahamskraal Formation

This lowermost formation of the Beaufort Group. Early Guadalupian in age, it corresponds to the Eodicynodon Assemblage Zone and to the Tapinocephalus Assemblage Zone.

3.2.2.3 The Beaufort Group

This is the third of the main subdivisions of the Karoo Supergroup of geological strata in Southern Africa. It follows conformably after the Ecca Group and consists essentially of sandstones and shales, deposited in the Karoo Basin from the Middle Permian to the early part of the Middle Triassicperiods. In the Eastern Cape Province the Karoo Basin fill commenced with the deposition of the Dwyka Group, followed by the Ecca Group, the Beaufort Group, the Molteno, Elliot, and Clarens formations of the Stormberg Group and the igneous Drakensberg Group.

3.2.2.4 The Bushveld Igneous Complex (BIC)

The Bushveld Igneous Complex (BIC) is a large layered igneous intrusion within the Earth's crust which has been tilted and eroded and now outcrops around what appears to be the edge of a great geological basin, the Transvaal Basin. Located in South Africa, the BIC contains some of the richest ore deposits on Earth. The complex contains the world's largest reserves of platinum-group metals (PGMs)—platinum, palladium, osmium, iridium, rhodium, and ruthenium (USGS, 2017), along with vast quantities of iron, tin, chromium, titanium and vanadium. Gabbro or norite is also quarried from parts of the Complex and rendered into dimension stone.

3.2.2.5 The Bushveld Sandstone Formation

This is a geological formation dating to roughly between 228 and 223 million years ago and covering the Carnian to Norian stages. The Bushveld Sandstone Formation is found in South Africa and is a member of the Stormberg Group. As its name suggests, it consists mainly of sandstone. Fossils of the prosauropod dinosaur *Massospondylus* have been recovered from the Bushveld Sandstone.

3.2.2.6 Cape Flats

This is an expansive, low-lying, flat area situated to the southeast of the central business district of Cape Town. To many people in Cape Town, the area is known simply as "The Flats". In geological terms, the area is essentially a vast sheet of aeolian sand, ultimately of marine origin, which has blown up from the adjacent beaches over a period on the order of a hundred thousand years.

3.2.2.7 Cape Fold Belt

This is a fold and thrust belt of late Paleozoic age, which affected the sequence of sedimentary rock layers of the Cape Supergroup in the southwestern corner of South Africa (Shone and Booth, 2005). It was originally continuous with the Ventana Mountains near Bahía Blanca in Argentina, the Pensacola Mountains (East Antarctica), the Ellsworth Mountains (West Antarctica) and the Hunter-Bowen orogeny in eastern Australia. The rocks involved are generally sandstones and shales, with the shales (Bokkeveld Group) persisting in the valley floors while the erosion resistant sandstones (belonging to the Peninsula Formation) form the parallel ranges, the Cape Fold Mountains, which reach a maximum height of 2325 m at Seweweekspoortpiek.

3.2.2.8 Cistecephalus Assemblage Zone

This is a geological stratum and a faunal zone of the Beaufort Group, of the South African Karoo. The name refers to Cistecephalus, a genus of small burrowing, mole-like dicynodont, whose fossils have been found in that structure.

3.2.2.9 Dicynodon Assemblage Zone

This is a geological stratum and a faunal zone of the Beaufort Group, of the South African Karoo. The name refers to Dicynodon, a genius of dicynodoniantherapsid, the Permian Period and whose fossils have been found in that structure.

3.2.2.10 Dwyka Group

This the group of sedimentary geological formations laid down in the Karoo Basin of Southern Africa in the Late Carboniferous and possibly extending into the Asselian of the early Permian. It consists mainly of tillites, laid down along the sandy shorelines of swamplands. The Dwyka is the oldest and lowermost unit of the Karoo Supergroup that is recognized throughout sub-Saharan Africa. In the Carboniferous, southern Africa was part of Gondwana. During the Late Carboniferous the lithosphere underlying what is now the Karoo Basin migrated over the South Polar Region. This resulted in southern Gondwana being covered by a major ice sheet. As the ice sheet and subsequent glaciers melted, the sediments of the Dwyka Group were deposited in the newly formed basin.

3.2.2.11 Elliot Formation

This geological formation dating to roughly 210 to 190 million years ago and covering the Norian to Sinemurian stages. The Elliot Formation is found in South Africa and Lesotho and is a member of the Stormberg Group. It consists mainly of limestone, sandstone, and mudstone. Fossils of the prosauropod dinosaur Massospondylus have been recovered from the upper Elliot Formation.

3.2.2.12 Gondwanide Orogeny

This was an orogeny active in the Permian that affected parts of Gondwana that are by

current geography now located in southern South America, South Africa, Antarctica, Australia and New Guinea (Kleiman et al., 2009). The zone of deformation in Argentina extends as a belt south and west of the cratonicnucleous of Río de la Plata–Pampia (Tomezzoli and Japas, 2006).

3.2.2.13 KaapvaalCraton (Kalahari and Zimbabwe Craton)

The Kaapvaal Craton (centred on Limpopo Province in South Africa), along with the Pilbara Craton of Western Australia, are the only remaining areas of pristine 3.6–2.5 Ga (billion years ago) crust on Earth. Similarities of rock records from both these cratons, especially of the overlying late Archean sequences, suggest that they were once part of the Vaalbara supercontinent (Zegers et al., 1998). The Kaapvaal Craton covers an area of approximately 1,200,000 km2 (460,000 sq mi) and is joined to the Zimbabwe Craton to the north by the Limpopo Belt. To the south and west, the Kaapvaal Craton is flanked by Proterozoic Orogens, and to the east by the Lebombo monocline that contains Jurassic igneous rocks associated with the break-up of Gondwana. The crustal evolution of the Limpopo Central Zone can be summarised into three main periods: 3.2–2.9 Ga, 2.6 Ga, and 2.0 Ga. The first two periods are characterised by magmatic activity leading to the formation of Archaean Tonalite-Trondhjemite-Granodiorite (TTG) such as the Sand River Gneisses and the Bulai Granite intrusion. Early Proterozoic high-grade metamorphic conditions produced partial melting that formed large amounts of granitic melt (Chavagnac et al., 1999).

There is no indication that the Neoarchean to early Paleoproterozoic succession on the craton were sourced from the 2.65–2.70 Gaorogenic event preserved in the Limpopo Metamorphic Complex. However, younger late-Paleoproterozoic red bed successions contain zircons of this time interval as well as many ~2.0 Ga detrital zircons. This implies that the Limpopo Complex together with the Zimbabwe Craton only became attached to the KaapvaalCraton at approximately 2.0 Ga during formation of the Magondi Mobile Belt which in turn sourced the voluminous late Paleoproterozoic red beds of southern Africa (Beukes et al., 2004). Evidence of the horizontal layering and riverine erosion can be found throughout the Waterberg Massif within the Limpopo Central Zone.

3.2.2.14Komatii Formation

The Komatii Formation is a 3.475 billion year old rock formation, named after the nearby Komati River in South Africa. It is the type locality for komatiite, a high temperature, Magnesium-rich volcanic rock.

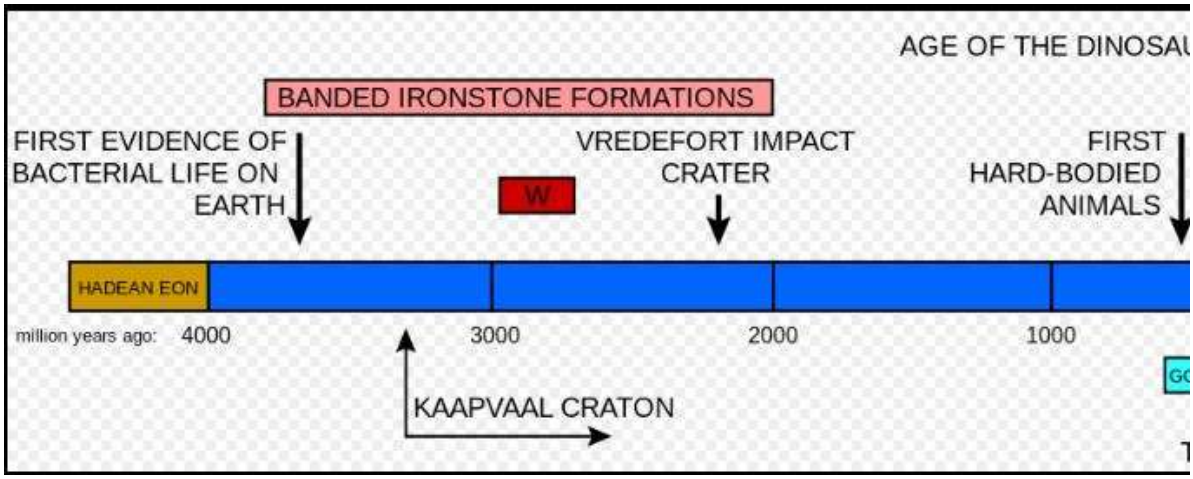


Fig 12 A timeline of the earth's geological history, with an emphasis on events in Southern Africa. The green block labeled K indicates when the Karoo Supergroup was deposited, in relation to the Cape supergroup, C, immediately before it. The W indicates when the Witwatersrand supergroup was laid down, very much further in the past. The graph also indicates the period during which banded ironstone formations were formed on earth, indicative of an oxygen-free atmosphere. The earth's crust was wholly or partially molten during the Hadean Eon; the oldest rocks on earth are therefore less than 4000 million years old. One of the first micro continents to form was the Kaapvaal Craton, which forms the foundation of the north-eastern part of the country. The assembly and break-up of Gondwana are, in terms of the earth's and South Africa's geological history, relatively recent events. Timeline of the earth's geological history with a Southern African emphasis. "W" indicates when the Witwatersrand supergroup was laid down, "C" the Cape Supergroup, and "K' the Karoo Supergroup (sources from https://en.wikipedia.org/wiki/Karoo_Supergroup).

3.2.2.15 Witwatersrand Basin

The Witwatersrand Basin was formed over a period of 360 Ma between 3074 and 2714 Ma. Pulses of sedimentation within the sequence and its precursors were episodic, occurring between 3086-3074 Ma (Dominion Group), 2970-2914 Ma (West Rand Group) and 2894-2714 Ma (Central Rand Group). Detritus was derived from a mixed granite-greenstone

source of two distinct ages; the first comprises Barberton-type greenstone belts and granitoids> 3100 Ma old, and the second consists of the greenstone belt-like Kraaipan Formation and associated granitoids≤ 3100 Ma old. Subsequent granitoidplutonism was episodic and coincided with hiatuses in sediment deposition, but continued throughout the evolution of the basin. Many of the provenance granitoids are characterized by hydrothermal alteration, are geochemically anomalous with respect to Au and U, and may represent viable source rocks for paleoplacer mineralization. Tectonically, the basin evolved in response to processes occurring within a Wilson cycle, associated with the encroachment and ultimate collision of the Zimbabwe and Kaapvaal cratons (Robb and Meyer, 1995), (Fig 12). Witwatersrand Basin is a classic example of where a variety of geological processes have coincided in time and space to produce the world's greatest gold province.

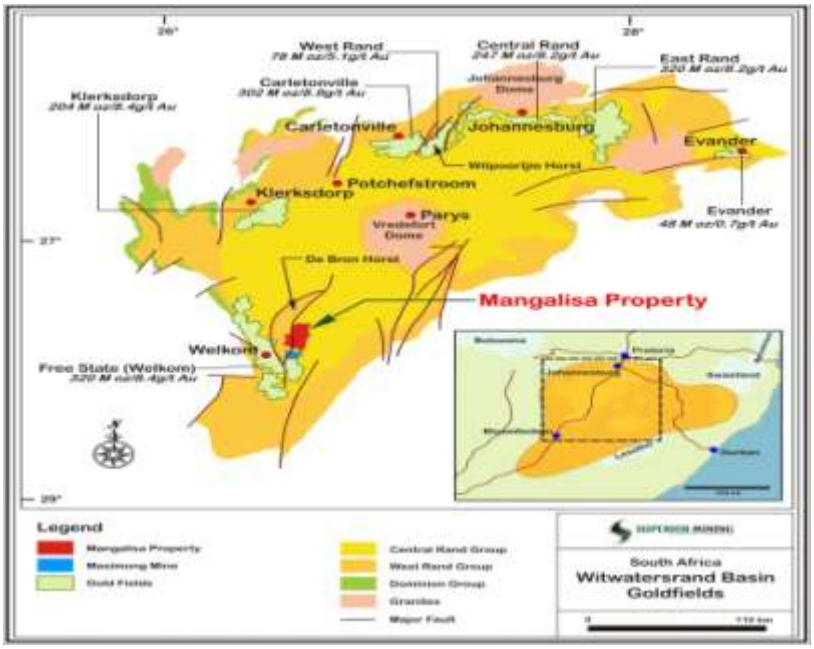


Fig11Witwatersrand goldfields and simplified geology(source:http://superiormining.com/properties/south_africa/)

4.0 Mineral Resources of South Africa

4.1 Geological Occurrence

Mineral resources in South Africa have been the main driving force (The Economist, 2017.behind the history and development of Africa's most advanced economy (The Economist, 2018). The country has about thirty officially extrusive mined minerals and many more still in the explanation stage. In 2013, South Africa's estimated share of world mined platinum production amounted to 72%; refined rhodium, 56%; refined platinum, 55%; chromium, 48%; kyanite and related minerals, 47%; mined palladium, 37%; vermiculite, 36%; vanadium, 27%; manganese.

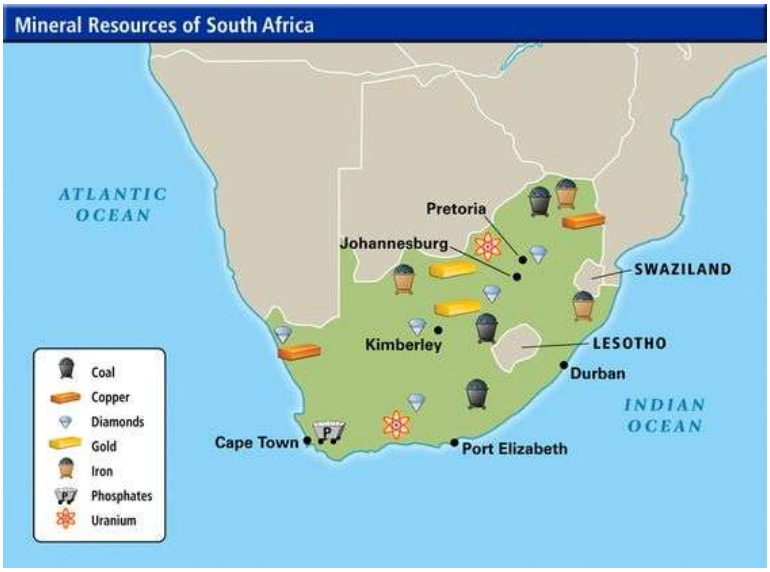


Fig 15 Mineral Resources of South Africa (source: https://www.pinterest.fr/pin/489133209503502769/)

Gold rushes to Pilgrim's Restand Barberton were precursors to the biggest discovery of all, the Main Reef/Main Reef Leader on Gerhardus Oosthuizen's farm Langlaagte, Portion C, in 1886, the Witwatersrand Gold Rush and the subsequent rapid development of the gold field there, the biggest of them all (F*ig 13).* Diamond and gold production may now be well down from their peaks, South Africa was number 1 (see Table 2 below) and 7 (see Fig 17) in gold production in the year 2000 and 2017 respectively (U.S. Geological Survey, Mineral Commodity Summaries, 2000 and 2018), but South Africa remains a cornucopia of mineral riches. It is the world's largest producer of chrome, manganese, platinum, and vermiculite. It is the second largest producer of ilmenite, palladium, rutile and zirconium. It is the third largest producers of vanadium. It is also the world's fifth largest coal exporter and 7th producer (IEA Coal Information, 2017 Overview). South Africa is also a huge producer of iron ore; in 2012, it overtook India to become the world third biggest iron ore supplier to China, who is the world's largest consumer of iron ore. Due to a history of corruption and maladministration in the South African mining sector, ANC secretary-general Gwede Mantashe announced at the beginning of 2013 that mining companies misrepresenting their intentions could have their licences revoked. Diamond and gold discoveries (Fig 15 and 16) played an important part in the growth of the early South African Republic. A site northeast of Cape Town was discovered to have rich deposits of diamonds, and thousands rushed to the area of Kimberley in an attempt to profit from the discovery. The British later annexed the region of Griqualand West, an area which included the diamond fields. In 1868, the republic attempted to annex areas near newly discovered goldfields, drawing protests from the nearby British colonial government. These annexations later led to the First Boer War of 1880-1881. Gold was discovered in the area known as Witwatersrand, triggering what would become the Witwatersrand Gold Rush of 1886. Like the diamond discoveries before the gold rush caused thousands of foreign expatriates to prospect and mine the region.

Fig 16 Locations of minerals in South Africa (Source: http://www.planetware.com/map/south-africa-south-africa-minerals-and-industries-map-saf-afs4.htm).

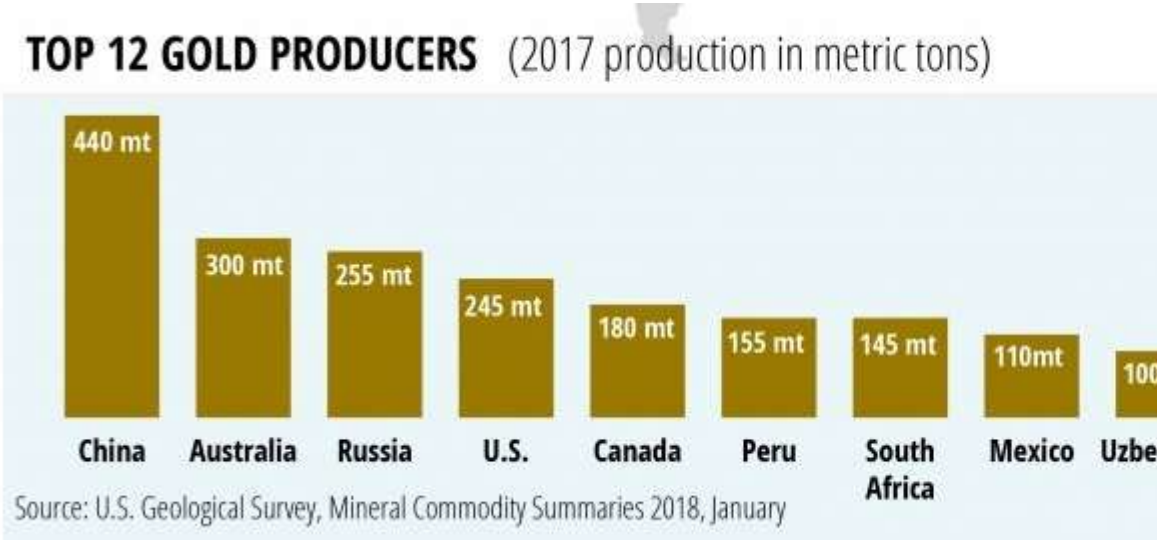


Fig 17. Top 12 Gold Producers Worldwide (2017), Source: U.S. Geological Survey, Mineral Commodity Summaries 2018, January.

This heightened political tensions in the area, ultimately contributing to the Second Boer War in 1899. Ownership of the diamond and gold mines became concentrated in the hands of a few entrepreneurs, largely of European origin, known as the Randlords. In old times, the gold mining industry continued to grow throughout much of the early 20th century, significantly contributing to the tripling of the economic value of what was then known as union of South Africa. In particular, revenue from gold exports provided sufficient capital to purchase much needed machinery and petroleum products to support an expanding manufacturing base. As at 2007, the South Africa mining industry employs 493,000 workers. The industry represents 18% of South Africa's $588 billion.

4.2 Mineral Wealth

South Africa's mineral wealth is typically found in the following well known geological formations and settings:a) The Witwatersrand Basin yield some 93% of South Africa's gold output and contains considerable Uranium, Silver, Pyrite and Osmiridium resources.
b) The Bushveld complex is known for Platinum group metals (with associated copper, nickel, and cobalt mineralization) chromium and vanadium-bearing titanium, iron ore formations and industrial minerals including fluospar and andalusite.d) The Trasvaal super group contains enormous deposits of manganese and iron ore.e) The Karoo Basin extends through Mpamalanga, Kwazulu-Natal, the free state as well as Limpopo, hosting considerable bituminous coal and anthracite resources.f) The Phalaborwa Igneous Complex hosts extensive deposits of copper, phosphorus, titanium, vermiculite, feldspar and zirconium ore, kimberlite pipes host diamonds that also occur in alluvial, fluvial, and marine setting.g) Heavy mineral sands contain ilmenite, rutile and zircon.
h) Significant deposits of lead-zinc ore associated with copper and silver are found in the Northern cape near Aggeueys.

4.2.1 Coal

South Africa is the world's fifth largest exporter and seventh producers of coal (IEA Coal Information, 2017). A considerable amount of butiminous coal and anthracite resources are hosted in the Limpopo basin, and much of the country's coal is used for power production (about 40%), about 90% of the energy used in the country is provided with coal.

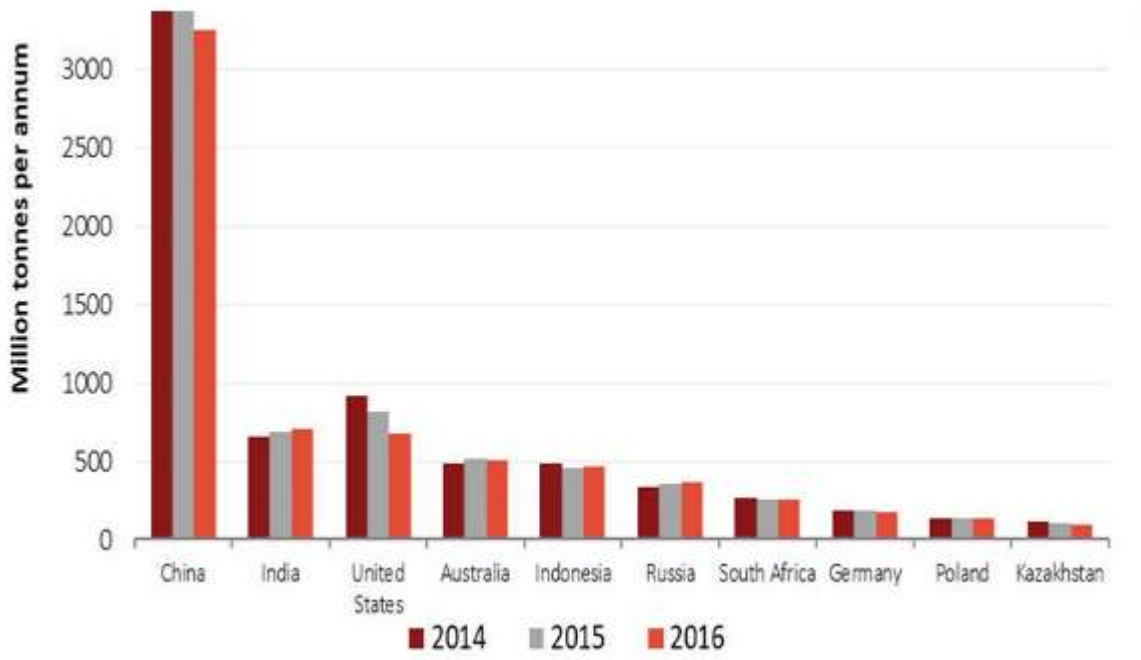


Fig18. Global Coal Production, Source: *Global top 10 producers of coal – IEA Coal Information 2017 Overview*

4.2.2 Gold

South Africa accounted for 15% of the world's gold production in 2002 and 12% in 2005. Although, the nation has produced as much as 30% of world output in 1993. Despite a decline in production, South Africa's gold exports were valued at $3.8 billion USD in 2005. According to the US Geological Survey, South Africa, in 2002, held about 50% of the world's gold resources and 38% of reserves, it is currently seventh in world gold production in 2017 (See Fig 17).Two of the nation's gold mines are ranked the deepest mines in the world; The East Rand mine, i.e. The Boksburg which extends to a depth of 3,585 metres (11, 762 ft). A 4-metre (13ft) shallower mine is located at Tantona in Carletonville, though plans are in place to begin work on an extension of the Tantona mine, bringing the total depths to over 3900metres (12,800ft) and breaking the current record by 127ft (39m). At these depths, the temperature of the rock is 140˚F (60˚C). The gold in the Witwatersrand Basin area was deposited in ancient river deltas, having been washed down from surrounding gold-rich greenstone belts to the north and west. Ever since the Kimberly diamond strike of 1868, South Africa has been a world leader in diamond production. The primary South African sources of diamonds, including seven large diamond mines around the country, are controlled by the De Beers consolidated mines company. In 2003, De Beers operations accounted for 94% of the nation's total diamond output or 11,900,000 Carats (2.38t). This figure includes both gem stones and industrial diamonds. Diamond production rose in 2005 to over 15,800,000 Carats (3.16t) (see Fig 15 and16).

4.2.3 Platinumand Palladium

South Africa produces more platinum and similar metals than any other nation ((U.S. Geological Survey, Mineral Commodity Summaries, 2018), see Fig. 19. In 2005, 78% of the world's platinum was produced in South Africa along with 39% of the world's palladium. Over 163,000 kilograms (5,200,0000zt) of platinum was produced in 2010, generating export revenues of $3.82 billion USD. Palladium is produced in two ways; recovery and mining production. Currently, Russia and South Africa are the biggest palladium producers in the world.

4.2.4 Chromium

Chromium is another leading product of South Africa's mining industry. The metal used in stainless steel and for a variety of industrial applications is mined at 10 sites around the country. South Africa's productions of Chromium accounted for 100% of the world's total production in 2005 and consist of 7,490,000 metric tons (7,370,000 long tons; 8,260,000 short tons) of materials.

4.2.5 Uranium

South Africa has around 6% of the world's developed uranium reserves and is the fifth largest reserves of uranium in the world (Slightlineu308, 2017). The nuclear fuels corporation of South Africa (NUFCOR) started processing uranium as a by-product of gold

mining in 1967. Most of the uranium produced as a by-product of gold mining is concentrated in the golf fields of the Witwatersrand area (See Fig 15 and 16). Uranium is more easily and readily available than gold in South Africa. There are a number of mining companies that process uranium from mines that they own. Anglo Gold Ashanti, Sibanye Gold ltd, Harmony Gold mining co, First uranium and Peninsular Energy, own or control most of the uranium as a by-product of gold from gold mining processing plants in South Africa. Though, uranium production in South Africa showed a decrease from 711t in 2000 to 579t in 2010, in 2011, 930t were produced with a forecast of 2000t by 2020. In 2016, Tasman Pacific minerals owned by Peninsula Energy stunted plans to open the first uranium ore mine, Tasman RSA.

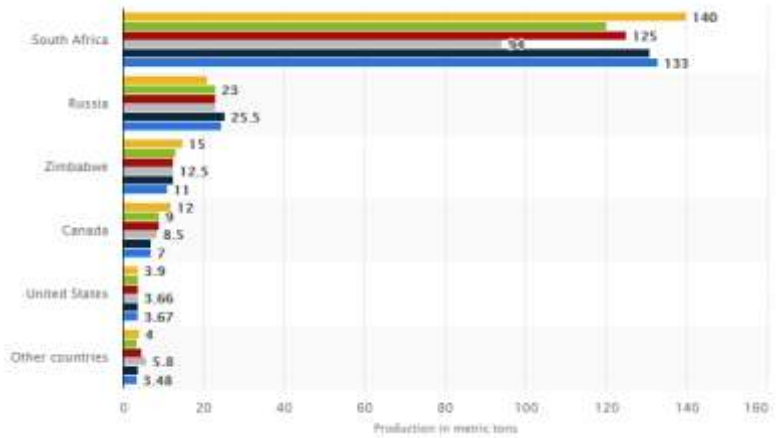


Fig 19. Major countries in global mine production of platinum from 2012 to 2017 (in metric tons). Source: Global platinum mine production of platinum; www.statista.com

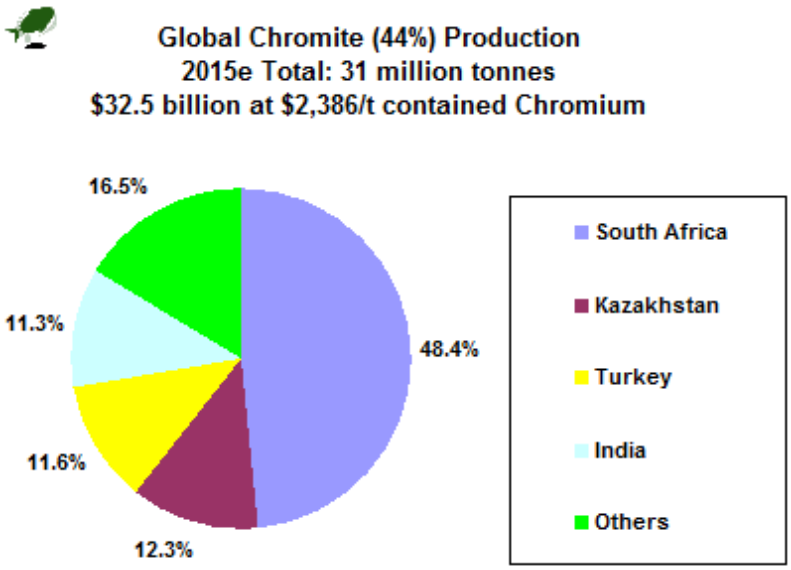


Fig 20. Global Chromite Production, Source USGS 2016,

4.2.6 Gypsum

Gypsum occurs in the northwestern part of the province. It is hosted by clay and occurs in the form of silimite crystal aggregate, powder, alabaster and satin spar veins. The gypsum bearing clay is derived from underlying bedrock of the Namaqua-Natal metamorphic province, Gariep Supergroup, Vanrhynsdorp Group and Whitehill formation. The clay has an average thickness of up to 4metres. In the region northwest of Vanrhynsdorp, approximately 4.5 million tons of gypsum has been mined since the 1930's leaving the remaining resources of 13 million tons. The application of gypsum is largely in the building industry as cement retarder, in plastic and ceiling boards and as a soil conditioner in the agriculture industry.

4.2.7 Limestone and Dolomite

Limestone is used for several applications including cement manufacture as a neutralizer of acid soils, 2, 11, 12, pure limestone is composed entirely of calcium carbonate, when it contains variable amounts of magnesium, it is called dolomite. Limestone in South Africa is confined to the Quartrenary Langebaan Formation. It comprises quartz-bearing limestone, calcareous sandstone and subordinate pedogenic calcite. Limestone occurs in the western and southern portion of the province and can be divided into high-grade and low-grade categories. The high-grade limestone occurs in the Congo group north of Oudtshoorn in the Malmesburg Group in the south-western part of the province and in the Gifbug And Vanrhynsdorp Groups in the vicinity of Vanrhynsdorp and Vredendal low-grade limestone occurs in the De Hoop Vlei, Wankoe and waenhuiskrans Formations of the Bredasdorp Group between Stoneford and Mossel Bay and in the Langebaan and Velddrif. Dolomite occur in the Malmesbury Group near Robertson and in the area southeast of Piketberg and in the Vanrhynsdorp Group in the region of Vredendal and Vanrhynsdorp.

4.2.8 Bentonite

It occurs in the five (5) rift related basins of the Late Jurassic to Early cretaceous age in the Cape Fold Belt between Rbertson and Plettenberg Bay. i) Robertson and Swillendan basin: Bentonite occurs in the Kirkwood Formation but no prospecting has been carried out. ii) Heidelberg-Riversdale Basin: Bentonite in the Kirkwood Formation is divided into two units; upper multicolored, pale greyish yellow and reddish sandstone and mudstone unit and a lower zone comprising olive-green and greenish grey mudstone and sandstone beds. The lower zone is up to 10m thick and hosts several bentonite horizons. iii) Mossel Bay Basin: Bentonite has been prospected with insignificant results iv) Plettenberg Bay Basin: Bentonite occurs in lenticular-topod-like bodies that vary in thickness from 0.15m to 2.5m and were mined between 1993 and 2004. v) Oudtshoorn Basin: Bentonite occurs in the Vitenwage Group but exploration has not been undertaken.

4.2.9 Phosphate

Phosphate in South Africa is confined to a single deposit on form numbers 9827km West of Africa. It consists of quartzose sand containing phosphatisec shell fragments in a matrix of cryptocrystalline francolite and formed in a shallow marine environment some five million

years ago. The average thickness is 1.5 metres and there is an overburden of sand of the Springfontein Formation between 3 and 4.5 metres thick. The deposit has not been developed and its principal application is for agricultural fertilizer.

4.2.10 Aluminum

South Africa produce primary aluminum from alumina imported from Guinea. BHP Billion ltd of Australia operated the Bayside and the Hillside primary aluminum smelters at Richards Bay. South Africa is not a major producer of aluminum which accounts for about 1.5% globally.

4.2.11 Antimony

The consolidated Murchison mine was South Africa's only producer of antimony in 2012 but output declined, simply because of labor dispute in July. In 2017, South Africa ranks seventh in the world's production of antimony (USGS, 2017), see Table 2.

4.2.12 Manganese

In 2013, manganese ore production was about 10.96Mt compared with 8.9Mt in 2012 and 3.55Mt in 2003 because of increased production from the Mamatwan and the Wessel mines and the opening of the Kalahari, the Kundumane and the Tshipi Borwa mines. From 2003 to 2013, employment in manganese mining increased to 9,866 workers from 2,623.In 2017, its production reduced to 5.3Mt (USGS, 2017), yet South Africa maintains its leading position in world production of manganese with a reserve of about 200Mt (See Table 2).

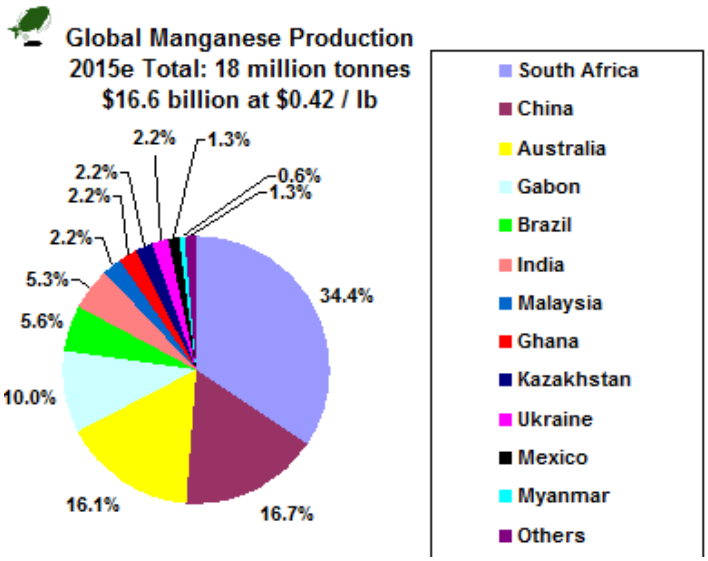


Fig 21. Global Manganese Production. Source: USGS 2016:https://secure.kaiserresearch.com/s1/SectoralTrends.asp?ReportID=300826

4.2.13 Iron ore and Iron and steel

In 2013, iron ore production was about71.5Mt compared with 67.1Mt in 2012 and38.1Mt in 2003 because of increased production from the Palahora and Sishen mines, the openings of the Khumani and the Kolomela mines from 2003 to 2013, employment in iron ore mining increased from 5,461 to 21,145 workers. Recently, South Africa ranks sixth (about 2.5%) world producers of iron ore (USGS, 2016).

TABLE 2.0: COMPARATIVE PRODUCTION/RANKING AND RESERVE FIGURES FOR SELECTED MINERALS AND METALS OF WHICH SOUTH AFRICA IS A MAJOR PRODUCER.

COMMODITY	SOUTH AFRICA			
	PRODUCTION 2017		RESERVES	
GOLD	145t	7	6,000t	15%
P.G.M	193t	1	63,000t	75%
DIAMONDS	2Mct	7	70Mct	-
CHROMITE	15,000Mt	1	200Mt	41.3%
MAGANESE	5.3Mt	1	200Mt	78%
VANADIUM	13,000t	3	3.5Mt	-
TITANIUM	1365t	1	71.3Mt	-
ZIRCONIUM	400,000t	2	14,000t	-
ANTIMONY	1200t	7	27,000t	-
ALUMINIUM SILICATES	NMP	-	-	1.5%
COAL	260Mt	7	9893Mt	1.3%
FLUORSPAR	200Mt	2	41Mt	-
VERMICULITE	170,000t	1	14Mt	-

SOURCES: MINING JOURNAL, MINERALS AND METALS ANNUAL REVIEW AND MINERALS BUREAU,IEA Coal Information 2017 Overview, PROVED COAL RESERVES IN SOUTH AFRICA; www.statista.com/statistics/265445/proved-coal-reserves-in-south-africa.

- *Platinum Group Metals (PGMs) includes platinum, palladium, rhodium, ruthenium, iridium and osmium*
- *Estimated percentage of known global reserves as per Minerals Bureau Statistics.*
- *NMP = Not a major producer.*
- *Mt = Million metric tons.*
- *Mct = Million carats.*

TABLE 3.0: SOME MAJOR MINING COMPANIES AND THEIR PRODUCTS IN SOUTH AFRICA

COMPANY NAME	MINERAL PRODUCT	REVENUE	NET INCOME	NUMBER OF EMPLOYEES
Anglogold Ashanti Limited	gold, silver, uranium oxide	US$5.334 billion (2010)	US $0.076 billion (2010)	62. 046 – june 2011
South 32 Limited	aluminium,	US$6.948 million	US $575	15.545 (2015)

5.0 Summary

In summary, South Africa's mineral wealth is typically found in the following; The Witwatersrand Basin yields some 93% of South Africa's gold output and contains considerable amount of uranium, silver, pyrite, and osmiridium resources. The Bushveld complex is known for PGMs (with associated copper, nickel, and cobalt mineralization), chromium and vanadium bearing titanium-iron-ore formations as well as large deposits of industrial minerals including fluorspar and andalusite. The Transvaal Supergroup contains enormous resources of manganese and iron ore. The Karoo Basin extends through Mpumalanga, Kwazulu-Natal, the Free state as well as Limpopo hosting considerable amount of bituminous coal and anthracite resources. The rocks of the Table Mountain, Bokkeveld and Witterberg of the cape supergroup follow unconformably upon the older rocks. South Africa is the world's largest producer of chrome, manganese, platinum, titanium and vermiculite. It is the second largest producer of fluorspar and zirconium. It is third largest in vanadium production. It is estimated to have the world's fifth largest mining sector in terms of gross domestic product (GDP) value. South Africa's mineral wealth at the end of 2016 is about R9.17 trillion (Chamber of Mines of South Africa's Department of Mineral Resources, 2016). South Africa's mineral wealth is typically found in the following; the Bushveld Complex which is the largest reserve in the world with over 100 million kilograms of PGMs, the Witwatersrand basin, which yields 93% of South Africa's gold output and contains considerable uranium, silver pyrite and The Phalaburwa Igneous complex hosts extensive deposits of copper, phosphate, titanium, vermiculite, feldspar, and zirconium ore. Kimberlite pipes host diamonds that occur also in alluvial, fluvial and marine settings. Heavy mineral sand contains limenite, rutile and zircon. Significant deposits of lead-zinc ores found in the Northern Cape near Aggeney.

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